

# CDF Electroweak Results: Summer 2004

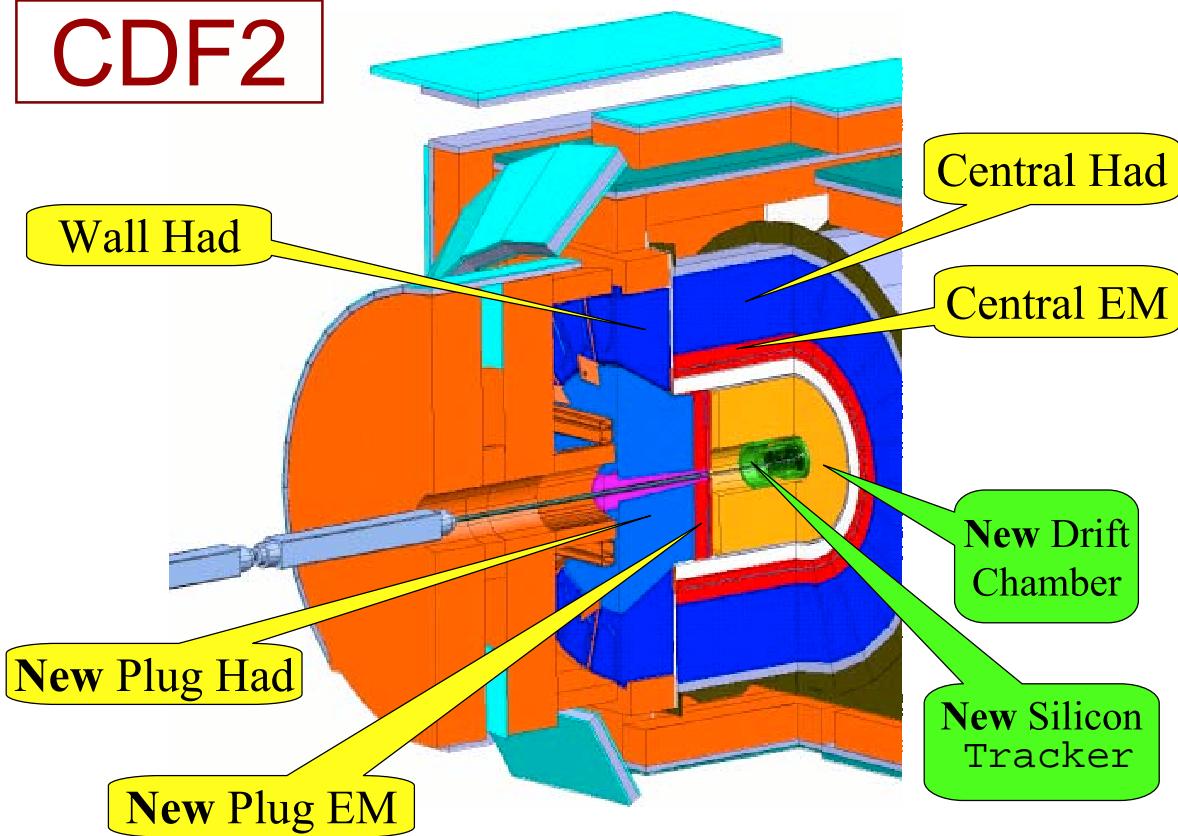
Willis Sakumoto, 09 Aug 2004

University of Rochester  
For the CDF Collaboration

- $W$ -Boson Mass
- $W$ -Boson Decay Width (Indirect)
- $W^\pm$  Production Asymmetry
- Top Mass
- Single Top
- Summary

# *W/Z Sample: Inclusive High $P_T$ Leptons*

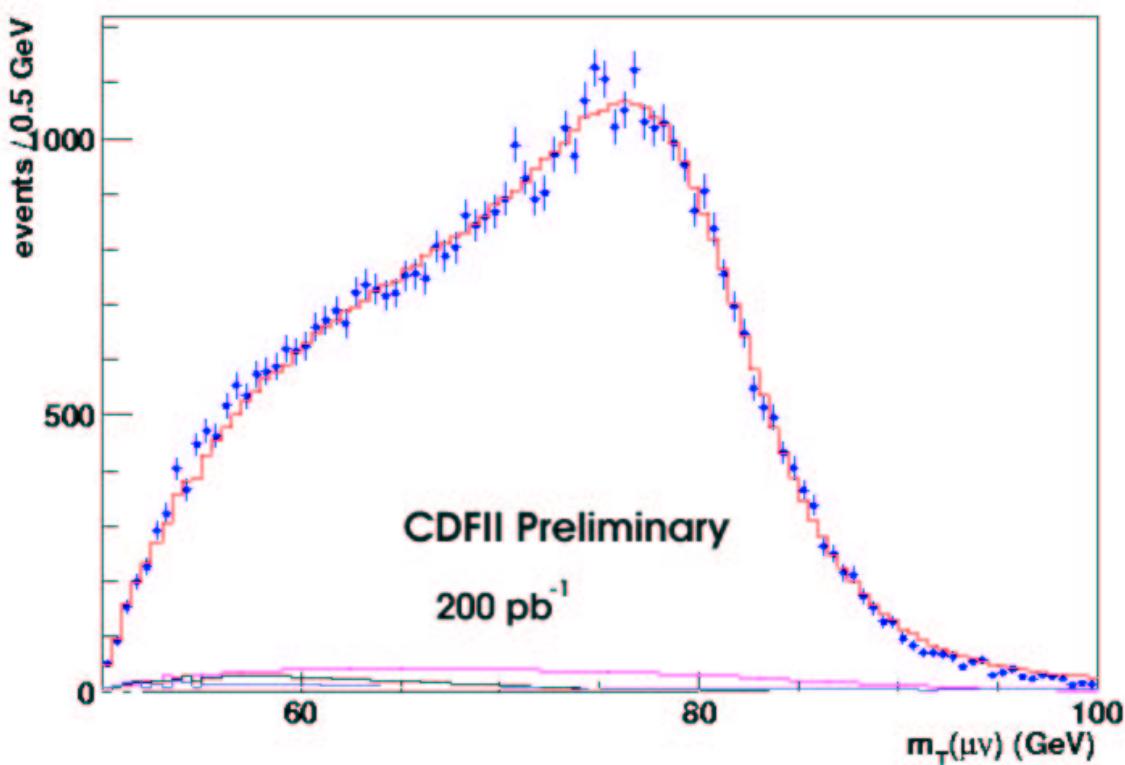
**CDF2**



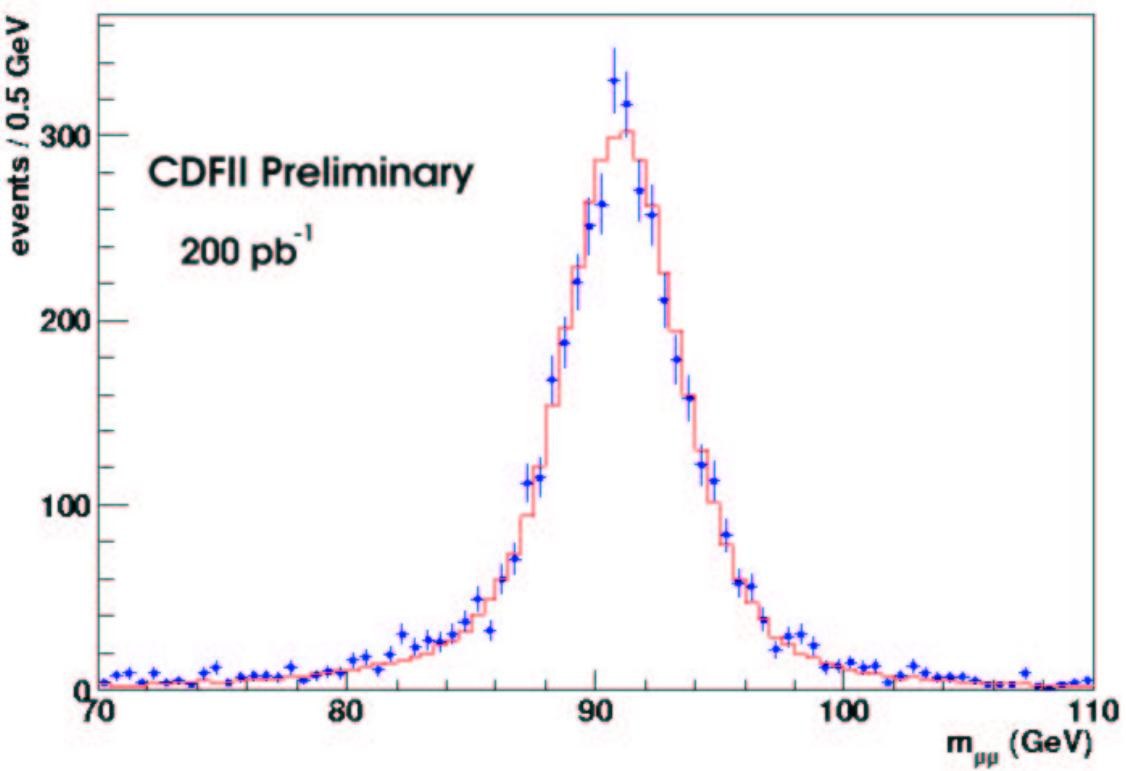
- Central leptons
  - $e$ :  $|\eta| < 1$
  - $\mu$ :  $|\eta| < 1$
  - Tracking and good particle ID
  - Required:  $W$  Mass,  $\sigma_W$ ,  $\sigma_Z$ , Single Top
- Plug electrons:  $1.1 < |\eta| < 2.8$ 
  - Tracking: Silicon + plug shower max

## **W-Boson Mass**

1. No preliminary results yet – expect to have them in several months
2. Status
  - All pieces of the analysis are in place
    - ResBos + WGRAD
    - Fast detector simulation
    - Mass fitter:  $M_T$ ,  $P_T(\ell)$ ,  $\not{E}_T$
  - Recently completed a full first pass
  - $W \rightarrow \mu\nu$ :  $M_T$



- $\gamma^*/Z \rightarrow \mu\mu$ :  $M_{\mu\mu}$



- The  $2 \text{ fb}^{-1}$  expectation:  $\delta M_W \simeq 40 \text{ MeV}$

## ***W*-Boson Decay Width (Indirect)**

### 1. Method

- Measure the Drell-Yan cross sections

$$\sigma \cdot \text{Br}(p\bar{p} \rightarrow W \rightarrow \ell\nu)$$

$$\sigma \cdot \text{Br}(p\bar{p} \rightarrow Z \rightarrow \ell\bar{\ell})$$

using high  $P_T$  electrons and muons

- From the measured  $W$ -to- $Z$  ratio,

$$\begin{aligned} R &= \frac{\sigma \cdot \text{Br}(p\bar{p} \rightarrow W \rightarrow \ell\nu)}{\sigma \cdot \text{Br}(p\bar{p} \rightarrow Z \rightarrow \ell\bar{\ell})} \\ &= \frac{\sigma_W}{\sigma_Z} \times \frac{\Gamma_Z}{\Gamma_Z(\ell\bar{\ell})} \times \frac{\Gamma_W(\ell\nu)}{\Gamma_W} \end{aligned}$$

derive  $\text{Br}(W \rightarrow \ell\nu)$  using the NNLO

$\sigma_W/\sigma_Z$  and LEP's  $\text{Br}(Z \rightarrow \ell\bar{\ell})$

- Systematics cancel or are reduced in ratios
- Using the SM prediction for  $\Gamma_W(\ell\nu)$ ,

$$\Gamma_W = \frac{\Gamma_W(\ell\nu)}{\text{Br}(W \rightarrow \ell\nu)}$$

## Inclusive W Cross Section

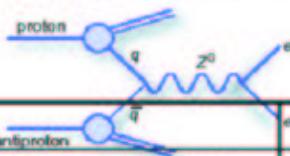


	e	$\mu$
Number observed events	37584	31722
Estimated Bkg events	$1656 \pm 300$	$2990 \pm 140$
Acceptance	$0.2397 \pm 0.0036$	$0.1970 \pm 0.0025$
Efficiency	$0.749 \pm 0.009$	$0.732 \pm 0.013$
Luminosity	$72.0 \pm 4.3 \text{ pb}^{-1}$	$72.0 \pm 4.3 \text{ pb}^{-1}$

$\sigma_W (\mu)$	$2768 \pm 16 \text{ stat} \pm 64 \text{ syst} \pm 166 \text{ lum (pb)}$
$\sigma_W (e)$	$2780 \pm 14 \text{ stat} \pm 60 \text{ syst} \pm 167 \text{ lum (pb)}$
$\sigma_W (e+\mu)$	$2775 \pm 10 \text{ stat} \pm 53 \text{ syst} \pm 167 \text{ lum (pb)}$

NNLO @  $\sqrt{s}=1.96 \text{ TeV}$ :  $2687 \pm 54 \text{ pb}$  (Stirling, van Neerven)

## Inclusive $\gamma^*/Z$ Cross Section



	e	$\mu$
Number observed events	4242	1785
Estimated Bkg events	$62 \pm 18$	$13 \pm 13$
Acceptance	$0.3182 \pm 0.0040$	$0.1392 \pm 0.0027$
Efficiency	$0.713 \pm 0.012$	$0.713 \pm 0.015$
Luminosity	$72.0 \pm 4.3 \text{ pb}^{-1}$	$72.0 \pm 4.3 \text{ pb}^{-1}$

$\sigma_{\gamma^*/Z} (\mu)$	$248.0 \pm 5.9 \text{ stat} \pm 7.6 \text{ syst} \pm 14.9 \text{ lum (pb)}$
$\sigma_{\gamma^*/Z} (e)$	$255.8 \pm 3.9 \text{ stat} \pm 5.5 \text{ syst} \pm 15.4 \text{ lum (pb)}$
$\sigma_{\gamma^*/Z} (e+\mu)$	$254.9 \pm 3.3 \text{ stat} \pm 4.6 \text{ syst} \pm 15.2 \text{ lum (pb)}$

NNLO @  $\sqrt{s}=1.96 \text{ TeV}$ :  $251.3 \pm 5.0 \text{ pb}$  (Stirling, van Neerven)

Note:  $\sigma_{\gamma^*/Z}$  over  $66 < M_{\ell\ell} < 116 \text{ GeV}$  is measured

## 2. Acceptance calculations

- We tune Pythia 6.203 to Run-I  $d\sigma/dy$  and  $d\sigma/dP_T$  measurements
- We use Pythia plus the full CDF detector simulation to get  $A_{e,\mu}(y)$ : the  $e, \mu$  acceptance in the boson rapidity  $\Rightarrow$  very slow
- We convolute a NNLO  $d\sigma/dy$  (Anastasiou, Dixon, et al.) with  $A_{e,\mu}(y)$  for the total acceptance:

$$\bar{A}_{e,\mu} = \sigma^{-1} \int \frac{d\sigma}{dy} A_{e,\mu}(y) dy$$

$\Rightarrow$  very fast – ideal for PDF error analyses

### 3. The $R$ ratios

$R(\mu)$	$11.12 \pm 0.27(\text{stat}) \pm 0.18(\text{syst})$
$R(e)$	$10.82 \pm 0.18(\text{stat}) \pm 0.16(\text{syst})$
$R(\mu + e)$	$10.92 \pm 0.15(\text{stat}) \pm 0.14(\text{syst})$
NNLO	$10.69 \pm 0.08$ : Stirling, van Veerven

Biggest systematic: PDFs–parton distribution functions

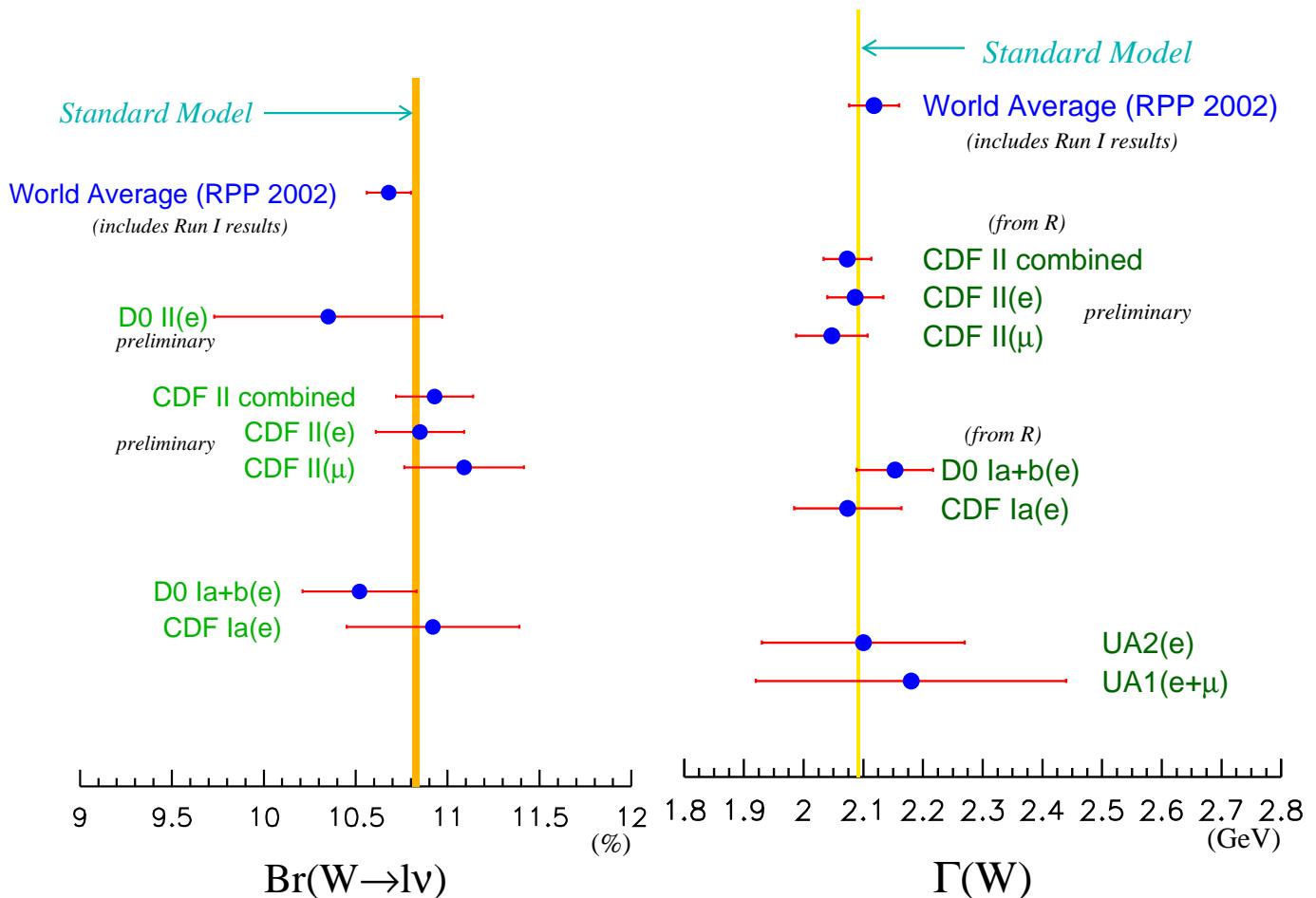
### 4. We extended the $\mu$ channel analysis to $194 \text{ pb}^{-1}$

$$\begin{aligned}\sigma_W &= 2786 \pm 12(\text{stat})^{+65}_{-55}(\text{syst}) \pm 166(\text{lum}) \text{ pb} \\ \sigma_{\gamma^*/Z} &= 253.1 \pm 4.2(\text{stat})^{+8.3}_{-6.4}(\text{syst}) \pm 15.2(\text{lum}) \text{ pb} \\ R &= 11.02 \pm 0.18(\text{stat})^{+0.17}_{-0.14}(\text{syst})\end{aligned}$$

and are working on the  $e$  channel

## 5. Extracted results: $72 \text{ pb}^{-1}$

Quantity	CDF II	World Avg
$\text{Br}(W \rightarrow \ell\nu)$	$0.1089 \pm 0.0022$	$0.1068 \pm 0.0012$
$\Gamma_W \text{ MeV}$	$2078.8 \pm 41.4$	$2118 \pm 42$
$\Gamma_W/\Gamma_Z$	$0.833 \pm 0.017$	$0.849 \pm 0.017$
$g_W(\mu)/g_W(e)$	$0.998 \pm 0.012$	$0.993 \pm 0.013$



## $W^\pm$ Production Asymmetry

### 1. $W$ -boson production at the Tevatron

- Parton level:  $u(p) + \bar{d}(\bar{p}) \rightarrow W^+$
- Since  $\bar{x}_u > \bar{x}_d$ 
  - $W^+$ : rapidity skewed in  $p$  direction
  - $W^-$ : rapidity skewed in  $\bar{p}$  direction
- The  $W^\pm$  rapidity ( $y$ ) asymmetry

$$A_W(y) = \frac{d\sigma/dy(W^+) - d\sigma/dy(W^-)}{d\sigma/dy(W^+) + d\sigma/dy(W^-)}$$

probes the PDF  $u(x)/d(x)$  ratio

- It could reduce PDF systematics for  $\Gamma_W$

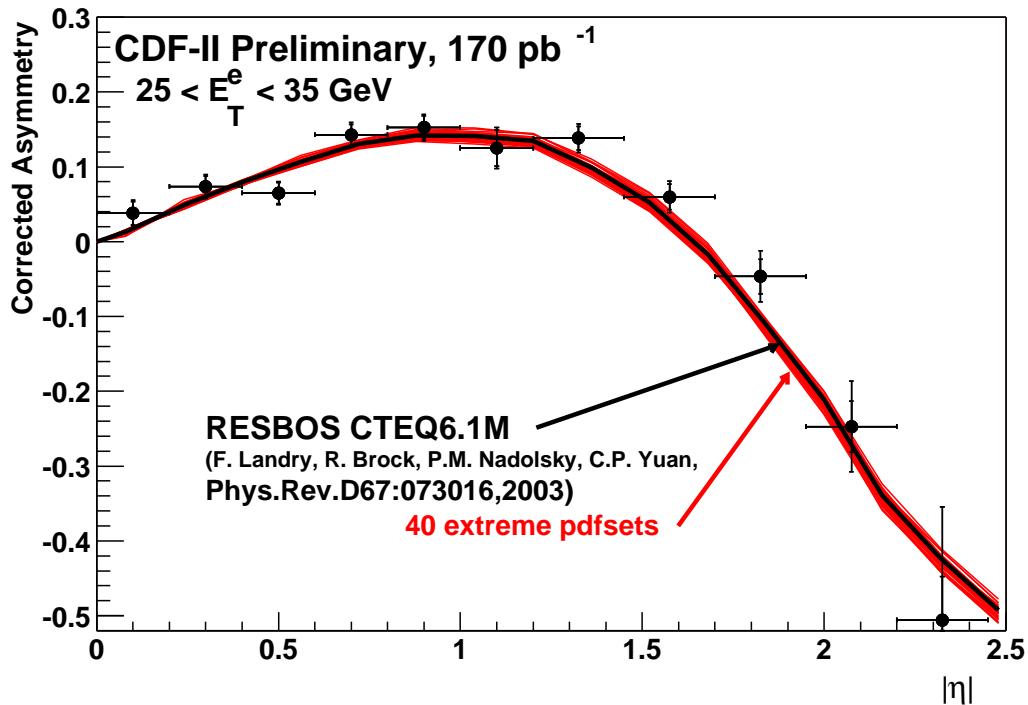
### 2. From $W \rightarrow e\nu$ decays, we measure the $e^\pm$ asymmetry

$$A(\eta) = \frac{d\sigma/d\eta(e^+) - d\sigma/d\eta(e^-)}{d\sigma/d\eta(e^+) + d\sigma/d\eta(e^-)}$$

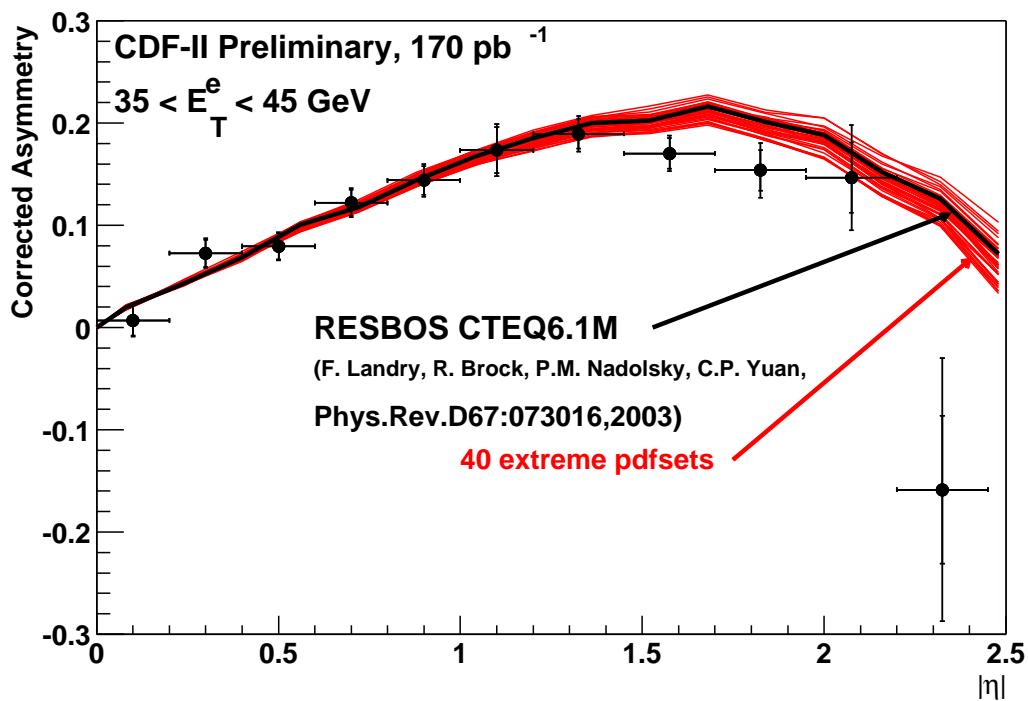
using tracked, high  $E_T$   $e$ 's with  $|\eta| < 2.5$

- It is still sensitive to  $A_W(y)$
- Is it a ratio: systematics cancel (eg, lum)

### 3. $A(|\eta|)$ : $25 < E_T^e < 35$ GeV



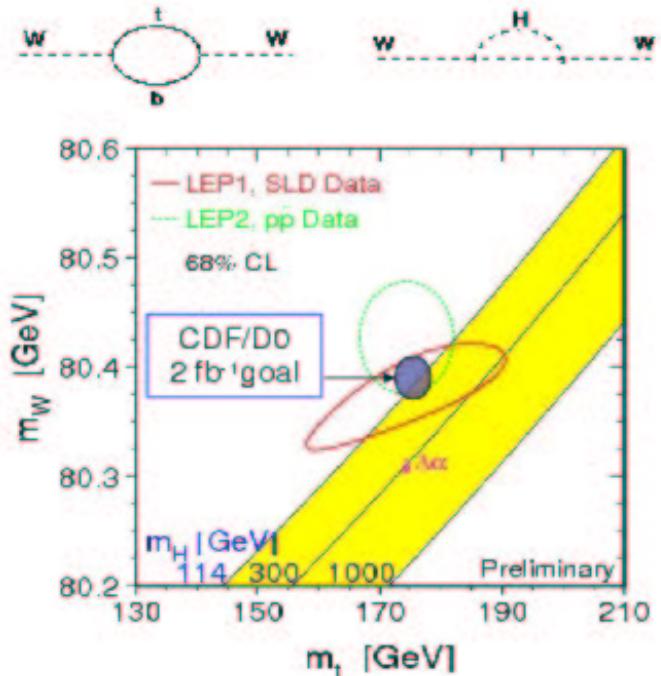
### 4. $A(|\eta|)$ : $35 < E_T^e < 45$ GeV



# Top Mass

1. Top mass goal:  $\delta M_t \simeq 3$  GeV

- Fundamental parameter
- Enters into a variety of electroweak calculations at one loop level
- Example: W mass receives quantum corrections proportional to  $M_t^2$  and  $\log(M_H)$
- Highly correlated with  $M_H$  in the current precision SM fit



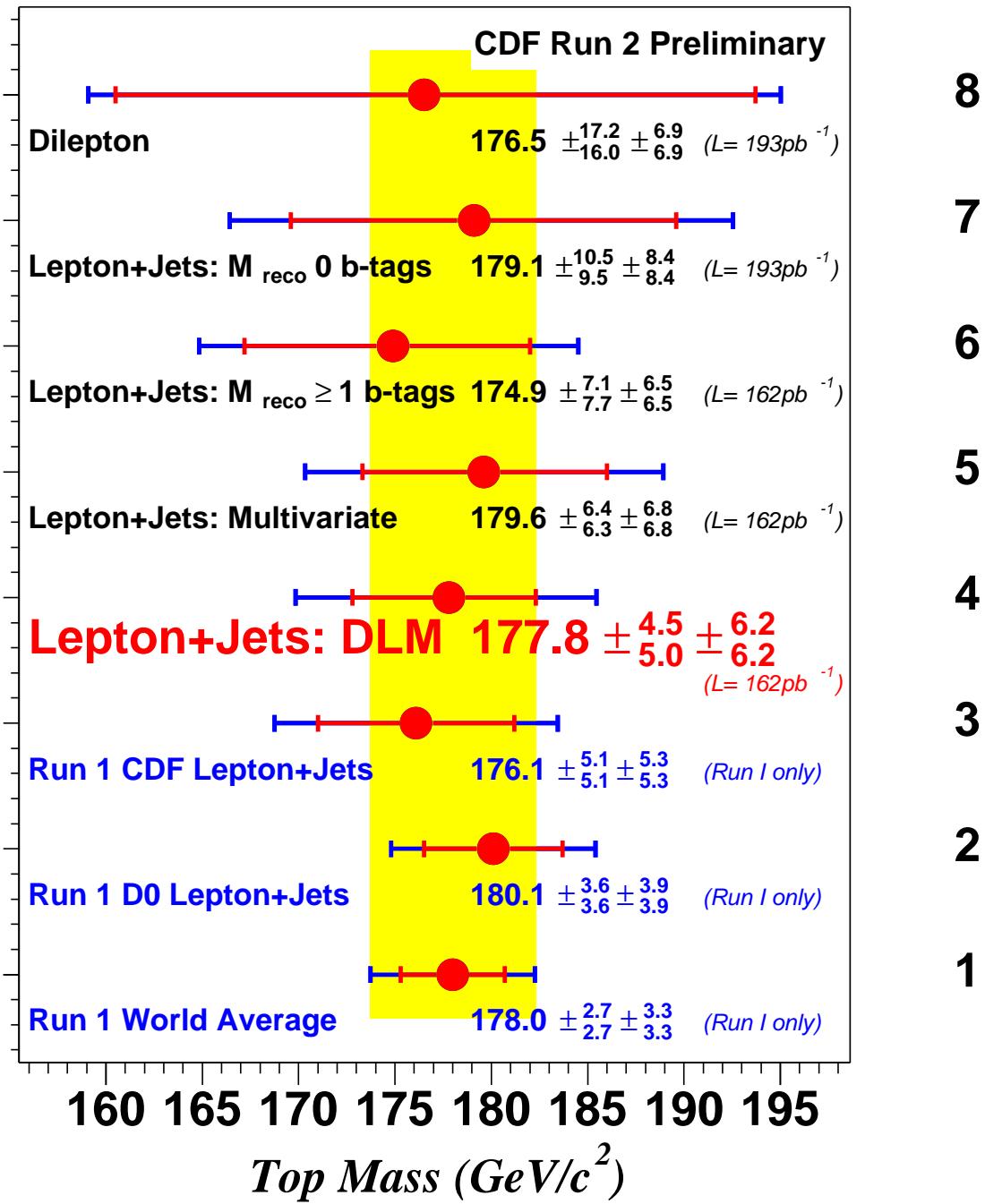
2. Event selection: “Lepton + Jets”

- W selection
  - Single isolated  $e, \mu$ :  $E_T(P_T) > 20$  GeV
  - $\cancel{E}_T > 20$  GeV
- Jets:  $E_T > 15$  GeV,  $|\eta| < 2$
- $b$ -tag jets: displaced vertex identified in silicon, usage depends on analysis

### 3. CDF Top mass methods

- TM: Template method (Run I method)
  - Kinematic fitter—reconstruct top mass
  - Kinematic constraints
  - Use best of 12 (4 if 2  $b$ -tags) combinations:
    - $b, \bar{b}, q, \bar{q}', \nu_{z1}, \nu_{z2}$
  - 1-dimensional templates—functions of  $M_t$
- MTM: Multivariate template method
  - Refined kinematic fitter with jet energy scale optimization
  - Kinematic constraints
  - Use all 6 (2 if 2  $b$ -tags) combinations:
    - ▷ Pick  $\nu_{z1}$  or  $\nu_{z2}$  with smallest  $|M_t - M_{\bar{t}}|$
    - ▷ Weight according to permutation probability ( $\Delta\chi^2$  between permutations)
    - ▷ Weighting improves  $M_t$  resolution
  - Multidimensional non-parametric templates
- DLM: Dynamical likelihood method
  - Matrix element method
    - ▷ Assumes Standard Model (SM)
    - ▷ Parton likelihood: from SM
  - Use all 12 (4 if 2  $b$ -tags) combinations
  - Transfer functions: observables  $\rightarrow$  partons

## 4. Summer 2004 results



## 5. Summer 2004 event counts

Method	Events
TM Dileptons	13
TM = 0 $b$ -tag	39
TM $\geq 1$ $b$ -tag	28
MTM $\geq 1$ $b$ -tag	33
DLM $\geq 1$ $b$ -tag	22

## 6. DLM events and background estimates

	No. of events
$W$ +light flavor	$1.2 \pm 0.37$
$Wbb$	$0.7 \pm 0.29$
$Wcc$	$0.3 \pm 0.12$
$Wc$	$0.2 \pm 0.12$
Single top	$0.17 \pm 0.03$
$WW$	$0.08 \pm 0.05$
QCD	$1.6 \pm 0.38$
Total Bkg	$4.2 \pm 0.71$
$t\bar{t}$ : 6.7pb	20.9
Observed	22

## 7. DLM systematic error sources

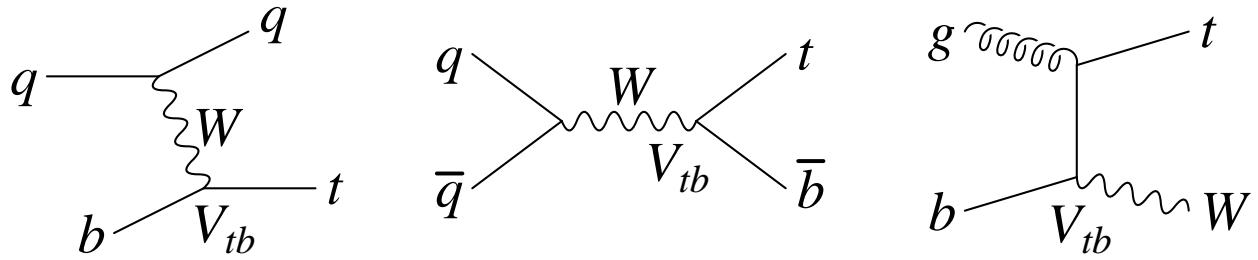
Source	$\delta M_t$ GeV
Jet Energy Scale	5.3
ISR	0.5
FSR	0.5
PDFs (parton)	2.0
Generator	0.6
Spin correlation	0.4
NLO effect	0.4
Transfer function	2.0
Bkg fraction ( $\pm 5\%$ )	0.5
Bkg modeling	0.5
MC modeling	0.6
Total	6.2

Jet Energy Scale: 5.3 GeV !?

- 1) Central Jet Energy Scale
  - 2) Relative Corrections vs  $\eta$  to Central
  - 3) Jet Energy nonlinearity
  - 4) Out of cone
- Big improvements to 1, 2 are upcoming
  - Working on upgrading 3, 4 (from Run I)

## Single Top

1. Single top production:  $\sigma_{t,\bar{t}}$



- Electroweak production
- Measuring  $\sigma_{t,\bar{t}}$ : direct extraction of  $|V_{tb}|^2$
- Large backgrounds: Lepton + 2-jet topology
- Small cross section

Channel	NLO $\sigma_{t,\bar{t}}$
s-channel	$0.88 \pm 0.11$ pb
t-channel	$1.98 \pm 0.26$ pb

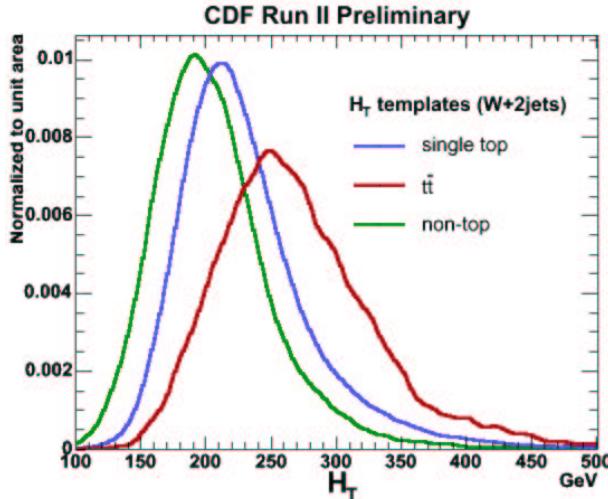
B.W. Harris et al. PRD 66, 054024

Z.Sullivan hep-ph/0408049

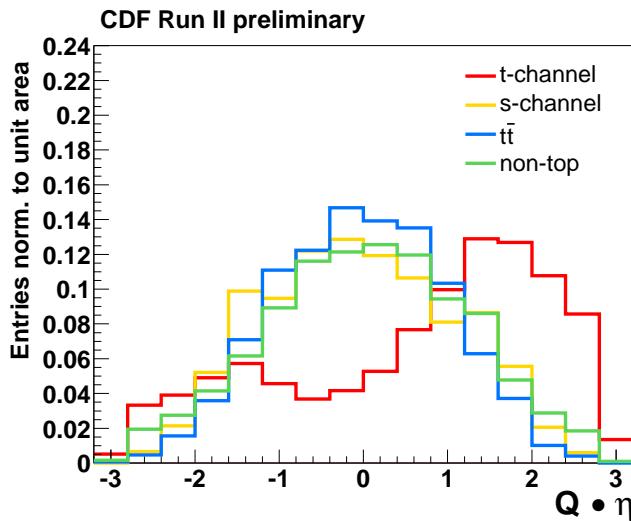
2. Analysis overview

- Event selection
  - Similar to top mass Lepton + Jets
  - Exactly 1 lepton (no dileptons)
  - Exactly 2 jets:  $E_T > 15$ ,  $|\eta| < 2.8$
  - $\geq 1$   $b$ -tagged jet

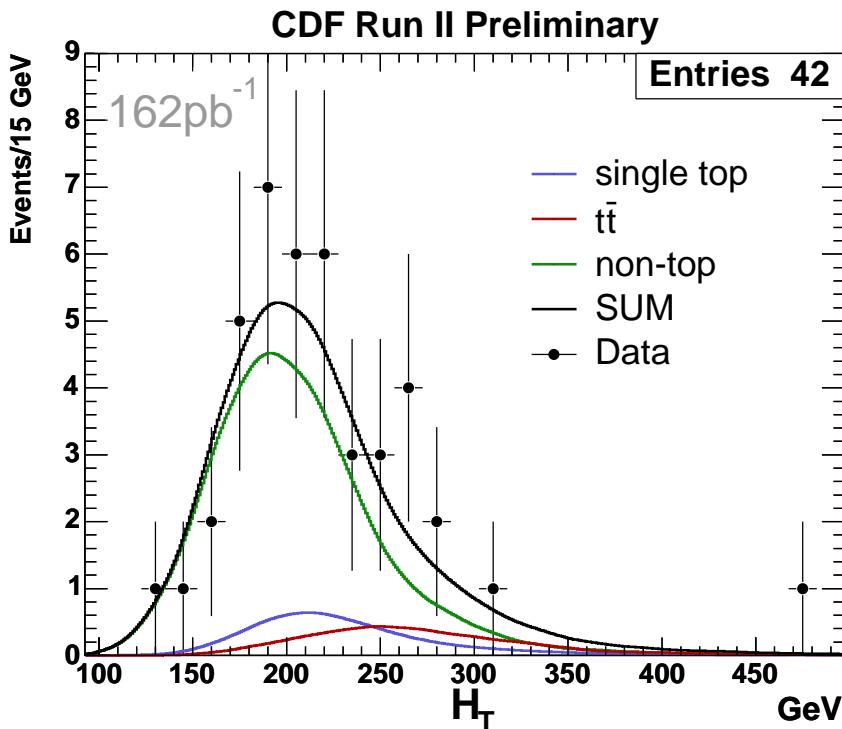
- Topological cuts to enhance S/B
  - $140 < M_{\ell\nu b} < 210$  GeV
  - Leading jet  $E_T > 30$  GeV (t-channel)
- Search strategy
  - Combined s,t-channel search:  
Fit  $H_T$ : scalar sum of  $\cancel{E}_T$



- Separate s,t-channel search  
Fit  $Q(\text{Lepton}) \cdot \eta(b \text{ Jet})$



### 3. No observation yet of single top: $\mathcal{L} = 162 \text{ pb}^{-1}$



### 4. Upper limits

	Run II 95% CL limits	Run I 95% CL limits
Combined	17.8 pb	14 pb
s-channel	13.6 pb	18 pb
t-channel	10.1 pb	13 pb

Improvements:

- Better Monte Carlo: MadEvent → Pythia
- Full Bayesian treatment of systematic errors in likelihood function

## Summary

- $W$ -Boson Mass: stayed tuned
- $W$ -Boson Decay Width (Indirect)
  - $\sigma_Z$ ,  $\sigma_W$ ,  $\Gamma_W$ : consistent with SM
  - Improvements: must lower systematics (PDFs)
- $W^\pm$  Production Asymmetry
  - Provides new constraints on PDFs
  - Most pronounced at high  $E_T$  and  $\eta$
- Top Mass
  - Already at our Run I precision level
  - Improvements are coming
- Single Top Production
  - No observation yet with  $162 \text{ pb}^{-1}$
  - Limits are improved over CDF Run I
  - Poised and ready